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Utilization of Cocos Nucifera Fiber Bonded with Paper Pulp as Composite Acoustic Panel Board

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Abstract:

Through the years, coconut (cocos nucifera) trees had various purposes in the field of engineering and were used in different construction materials especially in timber structures. Coconut husks were often seen as waste since these were disposed of after the coconut meat and milk were consumed. Despite this, it contains properties compatible for acoustic panel boards. Early studies proved the sustainability of using coconut fiber as alternative material for acoustic panel boards. This carries a positive impact on the environment as it lessens the usage of toxic chemicals. Previous research has highlighted coconut fiber as alternative material for sound absorption containing effectiveness in reducing noise levels, sustainable as renewable byproducts, and their capacity to resist fire. These align with the goals of environmental conservation and engineering innovation, offering a dual-purpose solution which addresses the objectives of this research. Paper pulp was used as a binder for acoustic panel boards since it contains properties suitable for sound absorption. It also possesses a positive impact on the environment as it helps in reducing the effects of greenhouse gasses. This research aims to assess the viability of coconut fiber and paper pulp as alternative materials for acoustic panel boards, considering moisture absorption, sound absorption, and fire resistance.

Keywords **—Cocos Nucifera, Construction Materials, Coconut Husk, Acoustic Panel Boards, Coconut Fiber, Sound Absorption, Noise Level, Renewable Byproducts, Paper Pulp, Moisture Absorption, Fire Resistance**

I. INTRODUCTION:

The use of composite cementitious natural fibers was considered in construction materials as an alternative panel board due to several advantages, including the possible reduction of solid waste disposal in the environment and higher various qualities in terms of physical and mechanical properties. One of the potential materials in the utilization of panel boards was the integration of natural fibers in place of steel and synthetic fibers, and coconut fiber and pulp paper gained prominence with the need to produce sustainable materials in construction. Subsequently, coconut coir and pulp paper were viable to be used as main materials to minimize the environmental impact by producing acoustic absorbing systems as panel boards.

With the rapid urbanization and transportation growth, noise pollution became a concern. The general public recognized that noise had a substantial effect on a person's well-being. Additionally, in their work efficiency, noise was a disturbance that could lead to psychological problems [1]. Therefore, it was important that the noise level in the living environment be kept under control. Sound absorption material absorbed sound wave energy and helped dissipate noise, which was an important approach for reducing noise levels.

Acoustic absorbing panel boards for treating a room were commonly made of porous synthetic fiber materials that were costly to produce, such as fiberglass, glass wool, polyurethane, and mineral wool. Fibrous materials have had a substantial impact in the engineering and construction industry due to their versatile applications in sound and thermal insulation. The primary materials used in the production of acoustic panels with effective and high sound absorption capabilities were glass fiber and mineral wool. While these synthetic materials effectively provided acoustic insulation, they also presented certain health risks to individuals. Natural fibers have a much lower environmental effect compared to synthetic materials. Conversely, there was a growing focus on natural materials as people became more aware of the detrimental impact these materials had on the environment and the potential health hazards they presented [2]. Nevertheless, there was little knowledge about the acoustic absorption properties of natural materials.

II. REVIEW OF RELATED LITERATURE

Natural resources such as coconut husks are not used in the food sector since they are not consumed by humans, who only consume coconut flesh and coconut milk. The Philippines is reputed to possess the highest quantity of coconut trees globally, and among the several coconut byproducts, coconut shell, coconut husk, and coconut coir are prominent. According to relevant research, over 500 million coconut trees produce 4.1 million tons of husk and 1.8 million tons of shell [3].

Coconut husk fibers are natural fibers obtained from the outer shell of a coconut, which are usually used for various objects found in houses. Since it is a natural material, it contains primary features of fabric such as mineral fiber related to and connected with sound-absorbing materials, which is why it is used as an alternative material for synthetic fibers. Moreover, acoustic panel boards made from coconut fibers produce a more natural, relaxing, and breathable style acoustic panel [4].

Natural fibers absorb sound waves weakly at low frequencies but are good passive absorbers at medium and high frequencies. Panels with a density of 200 kg/m³ may absorb both low and high-frequency sound waves within the 100 Hz – 5,000 Hz acoustic frequency range, with a noise reduction coefficient greater than 0.4, according to tests on sound absorption coefficient [5]. The results of a related study regarding the ability of CNF to absorb sound waves showed that the fiber contains an average sound absorption coefficient of 0.8 with a thickness of 20, 30, and 45 mm, and a frequency beyond 1360, 940, and 578 Hz, respectively [6].

In a study about the sound absorption characteristics of natural fibrous material, it was discussed that the sound absorption coefficient of coconut husk fiber varies in density and thickness. It was discovered that the capacity of coconut husk fiber to absorb sound under 1,500 Hz is at 0.5 and gradually increases as the frequency rises. The study showed that the density of the material has more influence than the thickness of the sample on the capacity of the sample to absorb sound. In addition, the higher the density and the thicker the sample, the greater its capacity to absorb sound.

Furthermore, the more fibrous the material is, the more it uses the energy from the sound pressure trapped in the material. Hence, a material with athickness of 20 mm and 0.1978 g/cm³ can absorb sound with 90%capacity under 3,000 Hz [7].

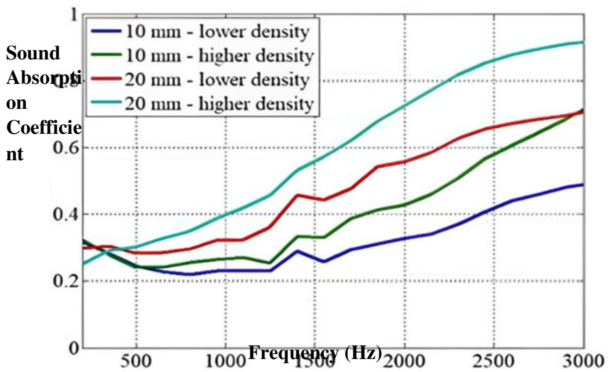


Figure 1. Coconut Husk Fiber Sound Absorption Coefficient

Several factors affect the acoustic performance of coconut husk fibers, including their type, fineness, length, orientation, density, volume fraction in the composite, thickness, level of compression, and design. Due to their porous structure, natural fiber composites have a notable ability to absorb sound [8].The benefits of using natural fibers in construction, such as their light weight, biodegradability, affordability, carbon neutrality, low energy consumption, and health benefits, have led to their widespread use in this field. Previous research has shown that natural fiber-based sound-absorbing materials have excellent acoustic qualities in high-frequency ranges, similar to synthetic fibers. Nevertheless, difficulties still exist due to their low strength, low fire resistance, high water absorption, and vulnerability to termite attacks, which prevents them from being used as building acoustic absorbers. Notwithstanding these disadvantages, natural fibers have demonstrated potential as synthetic fiber substitutes in this field, reducing some sustainability issues associated with using synthetic materials in building acoustics [9].

In recent times, there has been notable progress in developing natural materials with sound-absorbing properties, such as jute, arenga pinnata, hemp, and corn husk. This article specifically investigates the sound absorption attributes of coconut coir fibers when combined with polyurethane resin. A study utilized impedance tube setups as per ISO 10534-2 and ASTM E1050-98 standards across frequencies ranging from 100-5,000 Hz, wherein the study delves into the acoustic performance of coconut coir fibers with varying percentages of polyurethane resin (10%, 20%, 30%, and 40%). The research achieves an absorption coefficient of 0.95 at 3,200 Hz for a 40 mm thickness with a composition of 70% fiber and 30% resin, notably comparable to synthetic materials. Moreover, this sample surpasses another in the lower and middle frequency ranges, exhibiting coefficients of 0.4 (100-500 Hz) and 0.81 (500-1,900 Hz) [10].

Acoustic absorption material is necessary for reducing the sound intensity that a human can feel and hear to provide a more comfortable and peaceful living environment. Noise is considered an unwanted sound that yields and carries harmful effects to humans and animals [11]. Furthermore, silencers are also used to lessen the possibility of discomfort caused by unwanted sounds and are commonly used in various types of studios. However, these types of commercial sound absorption materials that have been used over the past years are known to be expensive, which is why several various alternatives were tested to substitute the material. In addition, coconut husk fibers are said to have almost the same property as an existing silencer. The capacity of the sound absorption of coconut husk fiber depends upon its thickness and porosity [12].

The effect of the intensity of sound imposes harmful effects on humans and animals. To provide comfort, acoustic absorption material is utilized to adjust the intensity. Comparing commercial and coconut fiber shows that the properties of the two materials almost have the same properties in terms of sound absorption. However, the advantage of using coconut husk fibers instead of commercial sound absorption material is that the negative impact on the environment is not as much.

Utilization of paper pulp as binder in wood briquette making is researched and was found out that it is an effective binder because of the moisture content of paper pulp ranging from 5%, 10%, and 15% [13]. A study shows recycled paper's capacity to absorb sound was not good at frequencies below 900 Hz but considerably improved after that point. Higher frequencies (above 900 Hz) were better masked by the more porous material, but lower frequencies (below 900 Hz) were less well-served by it. It's important to note that increasing the material's porosity alone didn't always improve its ability to absorb sound; instead, there appears to be a level of porosity at which recycled paper performs best as a sound absorber.Recycled paper outperformed other materials such as polyester and coir fiber, and for a given thickness, it was about half as good at absorbing sound as glass fiber [14].

Subsequently, the use of paper pulp as a binder was ascertained to have a significant effect in terms of moisture absorption. Paper pulp is more effective and efficient to be used as a binder since it has a great amount of moisture content. This property helps the binder to bond strongly as compared to dry properties since dryness impacts making the binder separate easily.

III. BACKGROUND OF THE STUDY

The Cocos Nucifera, a species of palm tree, is one of the world's most widely used palm trees and is frequently referred to as the "Tree of Life." Humans cultivated diverse coconut tree varieties in various regions, particularly the Philippines. This research examined the analysis of secondary data related to the cultivation of coconut trees and their benefits. The underutilization and disposal of coconut shells were the result of the increasing insect infestations and altering habitats that impacted the longevity of coconut trees. The presence of antiviral compounds in coconuts caused a substantial increase in the market for coconut products. Oils were produced from these adaptable trees, and their shells were utilized to produce materials, brooms, and timber for furniture, housing construction, and hardwood flooring. The cultivation of coconut trees had a profound impact on the lives of individuals worldwide; however, the persistent challenge was the management of the refuse produced by unused coconut shells [15].

With this, coconut husk was used as a sound absorption panel, having a great effect in conserving and maximizing the use of natural resources instead of disposing of them as waste. This type of agro-waste was suitable to use as a composite board, which helped mitigate various social and environmental issues, especially in the Philippines. Preservation of natural resources and innovating agro-wastes could reduce pollution and sustain our country’s economy as well. Moreover, coconut shells were known to be used in the Philippines as various things such as broom and furniture. Innovating it as a composite panel board diminished problem in the country not only in land or water pollution but also in noise pollution, which was a common problem everywhere.

The most impertinent type of interruption, according to some, was noise. Even worse, when noise disruption reached the level of noise pollution, it resembled other forms of pollution like air or water contamination. In fact, one of the top environmental dangers to health, according to a report issued by the World Health Organization (WHO) a few years ago, was ambient noise. Excessive noise resulted in several turbulences in the lives of many Filipinos as these types of pollutions could disturb their private and personal lives. With this, the innovation of composite panel board was essential and beneficial in reducing this type of problem in the country. The researchers aimed to lessen the impact of this problem by means of innovating a composite panel board consisting of organic waste materials.

The use of organic wastes was proven to be utilized effectively in different studies. One of the organic wastes used was the Coconut husks which were said to be more effective than sugar cane in terms of sound absorption and thermal insulation because coconut husks consisted of higher porosity which contributed to enhancing its ability to absorb sound and reduce heat [16].

Even in this era dominated by digital technology, paper retains its indispensability in the daily routines and professional pursuits of individuals, prompting concerns of excessive production that could generate unacceptable levels of waste, leading to pollution and potential health hazards for the populace. Nevertheless, conventional cellulose-based paper has been shown through various studies to possess remarkable sound-absorbing properties and enhanced fire resistance when compared to paper made from alternative agricultural waste materials [17]. Furthermore, studies have confirmed that paper pulp exhibits superior sound-absorbing properties compared to common agricultural waste found in our surroundings [14]. Additionally, research has shown that paper pulp boasts remarkable fire resistance, owing to its high-water absorption capacity, making it a suitable material for composite panels. In conclusion, this study affirms that the utilization of paper pulp is a more efficient approach for conducting research in this context.

In contemporary society, there has been a notable trend towards substituting synthetic materials utilized for acoustic absorption with more environmentally friendly alternatives, wherein the primary objective is to support ecological sustainability [18]. Agricultural residues are now being acknowledged as a viable resource for crafting cost-efficient sound-absorbing panels. These materials carry no inherent risks to human health and are readily available as byproducts within the agricultural cycle. Other studies endeavor to explore the acoustic attributes of diverse agricultural residue such as combinations of rice straw, bagasse, coconut husk, sugar cane fibers, and paper pulp [19].

Consequently, there was a growing need to explore more environmentally friendly alternatives for sound insulation panels. Natural fibers emerged as a promising option due to their abundance and durability. The production of coconut around the world was estimated to be approximately 60.5 billion kilograms in the year 2021. With 28% of the production, Indonesia was the top producer, followed by the Philippines with 24% [20]. From April to June 2023, the coconut yield amounted to 3.41 million metric tons, showing a yearly increase of 1.5 percent compared to the 3.36 million metric tons registered in the same quarter of 2022 wherein the Davao Region emerged as the leading producer of coconut, having a 13.5 percent share of the total yield followed by Northern Mindanao and Zamboanga [21]. The issue was that as demand for coconut products expanded, more garbage from them was produced. Some of this waste ended up in landfills without being properly managed, and some people burned it to make room for more agriculture.

Annually, the global recovery of paper amounted to more than 95 million metric tons. Within the Philippines, waste paper constituted 19% of the overall municipal solid waste, totaling 100 tons, with 40% of it ultimately being deposited in landfills. Highly urbanized cities such as Metro Manila showed a great percentage of paper usage which led to the generation of paper waste [22]. Notably, when biodegradable waste paper ended up in landfills, it generated methane under anaerobic conditions, a gas significantly more harmful to the environment, being more potent than carbon dioxide [23].

The disposal of agricultural waste, frequently in the form of stubble, via field burning, has led to substantial air pollution and environmental perils. Hence, the study also places significant emphasis on the development of environmentally-friendly thermal insulation materials using agricultural waste resources. The findings of this study indicate the promising potential of these innovative bonded fiberboards, including their hybrid variations, as natural materials suitable for both thermal insulation and sound absorption in construction applications

IV. METHODOLOGY:

The methodology which encompassed a sequential process commencing with data gathering, followed by the utilization of coconut coir fiber bonded with paper pulp as composite acoustic panel board. Subsequently, the framework advanced to material gathering and investigation, leading to material development, which culminated in laboratory testing. The testing phase rigorously evaluated sound absorption, moisture resistance, and fire resistance of the material. Following this, data analysis ensued, facilitating the progression to results and discussion. The conclusive phase of the framework involved deriving conclusions and formulating recommendations based on the comprehensive evaluation of the material's performance across the specified parameters

A. Research Design

In this study, the researchers aimed to employ product development through experimental design. Specimens were to be created, and tests were to be conducted to evaluate the materials capacities. It is a frequently used branch of scientific investigation in the development of new products and innovation by researchers. This approach allows for precise test design and execution to accurately analyze the relationships between variables [24]. The design of the experiment is experimental research design, suitable for this study because the specimens could be tested in a controlled environment, collecting all required data to analyze the results and assess the test materials capacities.

B. Research Methodology

Theresearch was conducted to use Cocos Nucifera Fiber (CNF) and Paper Pulp (PP) as an alternative to conventional acoustic panels. By explicitly mentioning: the 3 phases of the methodology (material collection & preparation, specimen development & testing and techniques for data recording & result analysis) During preparation of the samples CNF/PP materials were used, and during the production the equipment were the instruments. The researchers developed samples for experimental testing and produced molds for product shaping. By applying American Society of Testing and Materials (ASTM) and International Organization for Standardization (ISO) tests, they were able to glean the necessary data. Sound absorption was tested under a controlled environment as per ISO 10534-2, moisture absorption using ASTM D570 and fire resistance using ISO 11925-2.

C. Materials Collection

The researchers obtained Cocos Nucifera Fiber (CNF) by engaging local coconut vendors, negotiating to acquire the coconut husks, a byproduct of coconut processing containing the fiber. Once agreements were made, they proceeded to collect these husks, securing the primary material for the Acousti-Guard composite panel from environmental sources. Additionally, they adopted a sustainable approach for the binder, utilizing scrap papers to create paper pulp sourced from office, school, and residential papers through collaborations with institutions and companies. This method not only offered a cost-effective solution but also promoted environmental awareness by repurposing paper waste into valuable resources for the composite panel's production.

D. Development of the Acousti-Guard Panel Board

Fabrication of Acousti-Guard composite with Hadamard coded Cocos Nucifera Fiber (CNF) bonded with Orientation controlled Paper Pulp (PP) comprised of several stages. At first, the ratio of CNF to PP was optimized in order to achieve the predefined properties of a panel made of this composite. The choice of binder is also very important: sound absorption, moisture absorption and fire resistance are a few of the conditions that had to match the designers' requirements. To maintain cohesion, the fabrication involved compression and panel molding. This was then followed by full scale testing after fabrication of the panel to evaluate sound absorption, moisture absorption and fire resistance of the panel.

E. Research Procedure

The production of Acousti-Guard composite panels involved a sequential research process to properly assess and execute the composition and variables needed for the composite panel. The researchers divided this part into different portions to ensure that the production and development of Acousti-Guard provides an innovative acoustic panel.

1) Preparation of the Materials: The materials for the Acousti-Guard composite panel were meticulously prepared through a structured process involving Cocos Nucifera Fiber (CNF) and Paper Pulp (PP). Initially, coconut fibers were extracted from the husk and sun-dried for one to two days to achieve the optimal moisture content essential for the composite's integrity. Concurrently, paper waste was torn and soaked to form a pulpy texture, followed by a similar sun-drying process. Throughout manufacturing, the paper pulp acted as the binding agent, ensuring the cohesion of the composite material. This methodical approach preserved the natural acoustic properties of CNF and PP, setting the foundation for the development of a high-quality acoustic composite panel.

2) Preparation in Producing the Acousti-Guard: For the manufacturing process of the acoustic-guard, the CNF and PP are first individually weighed to determine their respective masses accurately. Once weighed, they are carefully placed into the molder, which has dimensions of 25cm by 25cm and various thicknesses of 2 cm, 3 cm, and 5 cm. Following this, the CNF and PP are bound together for the initial molding of the acoustic guard. Then, the polyurethane liquid (part A and part B) is weighed separately to determine the correct amount needed for the mixture. The polyurethane liquid is poured into the molder containing the CNF and PP. The molder is then sealed using the cover and clamped with a C-clamp to maintain the desired thickness of the acoustic guard while curing.

F. Research Sample

In this study, nine different samples with three varieties of thickness were used, each varying in the weight percentage composition of the materials. The dimension of the acousti-guard developed is 25 cm x 25 cm. Along with the objective of the study, the development and evaluation of the capacity of the samples were based on the percentage weight of the materials. The experimental samples of acoustic panel board produced were labeled as Acousti-Guard Sample A (2 cm), B (3 cm), and C (5 cm) and Specimen 1, 2 and 3 for the different design mixture under various thicknesses. Creating different specimens determined what the appropriate design mixture would be for achieving the most effective water absorption capacity, fire resistance capacity, and sound-absorbing capacity.

TABLE 1:
SAMPLE DESIGN MIXTURES FOR SAMPLE A

Acouti-Guard	Thickness	Specimen	CNF(%)	PP(%)	Resin(%)
A	2 cm	1	50	0	20
		2	60	20	20
		3	70	10	20

Sample A of the Acousti-Guard composite panel with a thickness of 2 cm and total mass of 200 grams comprises three different design mixtures designated as Specimens 1, 2, and 3. In Sample A-1, the composition includes 50% Cocos Nucifera Fiber, 30% Paper Pulp, and 20% Resin. Sample A-2 is composed of 60% Cocos Nucifera Fiber, 20% Paper Pulp, and 20% Resin. Sample A-3 consists of 70% Cocos Nucifera Fiber, 10% Paper Pulp, and 20% Resin.

TABLE 2:
SAMPLE DESIGN MIXTURES FOR SAMPLE B

Acouti-Guard	Thickness	Specimen	CNF(%)	PP(%)	Resin(%)
B	3 cm	1	50	0	20
		2	60	20	20
		3	70	10	20

The design mixture, measure by weight, for the 3 cm thickness of Acousti-Guard with mass of 290 grams consists of three different compositions, labeled as Specimen 1, Specimen 2, and Specimen 3, for Sample B. Like Sample A, Sample B-1 contains 50% Cocos Nucifera Fiber, 30% Paper Pulp, and 20% Resin. Sample B-2 comprises 60% CNF, 20% PP, and 20% Resin, while Sample B-3 is composed of 70% CNF, 10% PP, and 20% Resin.

TABLE 3:
SAMPLE DESIGN MIXTURES FOR SAMPLE C

Acouti-Guard	Thickness	Specimen	CNF(%)	PP(%)	Resin(%)
C	5 cm	1	50	0	20
		2	60	20	20
		3	70	10	20

For the 5 cm thickness and 450 grams weight Acousti-Guard Sample C, the design mixtures are outlined with the percentage of Cocos Nucifera Fiber (CNF), Paper Pulp (PP), and Resin. In Sample C-1, the composition consists of 50% CNF, 30% PP, and 20% Resin. Sample C-2 includes 60% CNF, 20% PP, and 20% Resin. Sample C-3 is composed of 70% CNF, 10% PP, and 20% Resin.

G. Moisture Absorption Test

The researchers followed the procedures for moisture absorption by panels of Acousti-Guard composite that are described in ASTM D570 (Moisture Absorption for Plastics). They started by preparing the dry samples and then recorded their initial wet weights. Samples were immersed in distilled or deionized water according to ASTM D570 and weighed periodically to determine the level of moisture absorption until saturation. After unsaturation, those samples were gently dried down to their original state and their ultimate weights were documented. A balance was then made and the percentage of the moisture absorption was measured according to ASTM D570 formula. Thus, the study investigated the moisture absorption behaviours exhibited by Acousti-Guard composite panels in more detail. This thorough examination involved interpreting the results in strict accordance with the standards outlined in ASTM D570, ensuring the utmost accuracy and reliability of the findings obtained.

H. Fire Resistance Test

The ISO 11925-2, standards for reaction to fire test, guidelines were followed in the process of assessing the fire resistance of Acousti-Guard composite panels. First, panel samples were prepared, ensuring they fit the standard's specified sizes. The procedure was configured in accordance with ISO 11925-2, taking into consideration the flame spread for the specified fire conditions. Throughout the test, the behavior of the fire is observed and the ability of the panel to resist fire. When the panels were exposed to the specified fire conditions, data was meticulously recorded. The endurance of the panels under the specified fire conditions was evaluated, and the panels were carefully inspected for any visible effects or structural damage following the test. A thorough report was created that explained the findings of the fire resistance testing done on Acousti-Guard composite panels in accordance with ISO 11925-2 by analyzing the gathered data, including temperature profiles. Adhering to ISO 11925-2 standards throughout the testing ensured the precision and reliability of the results of testing.

The fire testing starts with suppressing the product, preparing the blowtorch, and preparing the timer. After, the blowtorch is ignited and the product is exposed.

While the product is exposed, the researchers will observe for a total of 1 minute. Where the first 30 seconds is letting the product get exposed to the fire and the last 30 seconds to observe the effect of the fire to the product [25]. After the exposure of the sample on fire, the following is observed:

Classification	Test Method	Classification Criteria	Other Criteria
B	Fire Exposure 30 sec	Flame Spread ≤ 150 mm within 60 sec	-
C			Smoke Production / No Flame droplets
D		Flame Spread ≤ 150 mm within 20 sec	Smoke Production / No Flame droplets
E	Fire Exposure 15 sec	Flame Spread ≤ 150 mm within 20 sec	Smoke Production and Flame droplets
F	No Performance Determined		

- Whether the After flame-time lasted less than 3 seconds, AFT < 3 sec
- Flame spread below 150 mm and the time taken to reach 150 mm, Fs > 150 mm
- Presence of flaming droplets

TABLE 4:
FIRE RATING CLASSIFICATION FOR ISO 11925-2

The fire rating for materials is shown in Table 4, which adheres to the ISO 11925-2 standards. For classes B, C, and D, the materials are exposed to fire for 30 seconds. For classes B and C, the flame spread should be less than or equal to 150 mm within 60 seconds. For class D, the flame spread should be within 20 seconds, and smoke production is present. Materials with a class E rating are exposed to fire for 15 seconds, and the flame spread should be less than or equal to 150 mm within 20 seconds, with smoke and flame droplets present. For class F, no performance is determined, and it does not offer any fire resistance.

I. Sound Absorption Test

The Researchers strictly followed ISO 10534-2 standards to thoroughly evaluate the acoustic properties of our Acousti-Guard composite panels. It was like getting our panels ready for a close-up. They carefully set them up in the impedance tube to see how well they absorbed sound, reflected it, and handled surface impedance. They even tweaked the microphone positions to catch every little sound, even the ones from the tube itself! This method worked like a charm for our study and sample-making process because it didn't need a ton of acoustic material. We dove into recording sound levels across different frequencies, with and without the panels, to crunch the numbers and figure out those sound absorption coefficients, following ISO 10534-2's playbook. This hands-on approach really helped us understand just how good our panels are at soaking up sound, while also making sure we met ISO 10534-2's tough standards.

TABLE 5:
CLASSIFICATION FOR SOUND ABSORPTION

Sound Absorption Class	Sound Absorption Coefficient (α)	Class Definition
A	0.90, 0.95, 1.00	Extremely Absorbing
B	0.80, 0.85	
C	0.60, 0.65, 0.70, 0.75	Highly Absorbing
D	0.30, 0.35, 0.40, 0.45, 0.50, 0.55	Absorbing
E	0.15, 0.20, 0.25	Hard Absorbing
Not Classified	0.00, 0.05, 0.1	Reflecting

Table 5 shows the classifications for sound absorption, which vary based on their capacity to absorb sound. For class A, the sound absorption coefficient ranges from 0.90 to 1.00 and is described as extremely absorbing. In class B, a sample should have a sound absorption coefficient of 0.80 to 0.85 to be considered an extremely absorbing material. A sound absorption coefficient ranging from 0.60 to 0.75 is considered class C and highly absorbing. Class D's sound absorption coefficient ranges from 0.30 to 0.55, which is considered absorbing. Class E material is described as hard absorbing and has a sound absorption coefficient of 0.15 to 0.25. Moreover, materials that have a sound absorption coefficient of 0 to 0.10 do not absorb sound and are regarded as reflective materials.

1) Development of the Alternative Impedance Tube:In this study, impedance tube is developed to gather the values needed to identify the sound absorption factors of the samples. The impedance tube is the most important apparatus for this test and the values obtain the necessary measurement in developing the impedance tube is obtained using the standards under two-microphone transfer function method of ISO 10534-2

[26]. Utilizing this method, it is much simpler to conduct the test without the needs of complex rooms such as reverberation sound chamber and large quantity of sample. Furthermore, the gathered data from this experimentation method will exhibit different values in other studies due to different approach of setups on developing the materials and apparatus, especially the sample materials of this study. The difference of the value obtain on other studies may due to relation about the resistivity flow of the setup [27]. Other factors affecting the results is the material used in producing the impedance tube that may cause disturbance on the planar waves produced due to its surface [28]. Due to lack of testing centers for identifying sound absorption of a material, researchers utilize the standards under ISO 10534-2 and ASTM E-1050 to produce the impedance tube using available parts on the market.

2) Tube Specifications: The impedance tube is essential for performing sound absorption tests with the two-microphone transfer function technique. On one end is a speaker and the sample material is supported on the other end. It is the dimensions of the tube which control its frequency range and the diameter and length of the tube that can affect what types of frequencies can be measured. Using equations to determine the upper and lower frequency limits (based on the type of tube and the speed of sound in air).

$$f_u < \frac{Kc}{d} \text{ or } d < \frac{Kc}{f_u} \quad \text{Eq. 1}$$

$$f_l > 0.05\frac{c}{s} \text{ or } s < \frac{c}{f_l} \quad \text{Eq. 2}$$

The distance between the microphones is crucial as well and should be kept greater than 5 % of the wavelength of the lowest frequency intended to be used[28]. Furthermore, the tube should also be air-tight in order to not hinder the sound, and keep the efficiency. Cheapest microphones and PVC pipe were used for sound measurement with PVC sealant between connecting points.

3) Measurement Method: The study used a homemade impedance tube, along with an audio interface, amplifier, and omni-directional microphones to take measurements. Battery-powered microphones were hooked up to the audio interface, which sent frequencies to the computer. They employed MATLAB GUI software (A-lab) to generate frequencies and gather data, following the ISO 10534-2 standard for analyzing the material's sound absorption coefficient. This software was picked for its easy operation, speed, and better accuracy in obtaining results.

V. RESULTSANDDISCUSSIONS:

ThischapterexplainstheresultsthatwerecollectedthroughmechanicalandtechnicalproceduresthatwerediscussedfortheWaterAbsorptionTest, FireResistanceTest, andSoundAbsorptionTest. Alloftheproceduresweredonemanuallybytheresearchersinaccordancewiththe ISO and ASTM Standards stated on Chapter2. Thedatathatwerecollectedarepresentedintablesandgraphsincludingthedataanalysisandfindingsthatarebasedontheobjectivesofthestudy.

A. ExperimentResultsforMoistureAbsorption

Theresearcherssubmergedthesampleswithdifferentthicknessandratioonwaterandweightedthesampleindifferent lengthsofexposure. Foroptimalconditions, thesamplesweresubmergedinwaterthatis24 ± 1°Candwereconductedinacoolandwell-ventilatedplace. Thesamplesaresubmergedfor24hours, 48hours, and72hoursandaresundriedfor72hoursaftereverylengthofexposuretocompletelyremovethemoistureinsidethesamples. Therearemainfactorsthatareneededtobeconsideredinconductingthistestmainly, thelengthofexposure, ratio, andthicknessofthesample. Inordertoidentifythemoistureabsorptionofthesamplepanelthisequationisused,

$$Moisture\ Absorption\ (\%) = \frac{W_w - W_d}{W_d} * 100 \quad \text{Eq.3}$$

1)Results for 2 cm Thickness of Acousti-Guard:

TABLE 6:
MOISTURE ABSORPTION RESULTS OF ACOUSTI-GUARD SAMPLE A

Specimen	Moisture Absorption (%)			GWA
	24 hours	48 hours	72 hours	
1	126.34	160.75	202.69	163.26
2	164.47	218.27	251.78	211.51
3	196.52	237.81	268.66	234.33

ThecollecteddatafromTable6wereusedincalculatingthemoistureabsorptionofthesamples. For24hoursexposureofthe2cmthicknesssample, thespecimen1had126.34%, thespecimen2had164.47%, andthespecimen3had196.52%moistureabsorption. Moreover, forthe48-hourexposure, theAcousti-Guardobtainedamoistureabsorptionof160.75%forspecimen1, 218.27%forspecimen2, and237.81%forspecimen3. Asforthepanelsthatwereexposedfor72hours, therecordedmoistureabsorptionforspecimen1was202.68%, 251.77%forspecimen2, and268.65%forspecimen3. Basedontheresults, thethirdsampleobtainedthehighest contentofmoistureabsorptionforthissamplethickness. While, thespecimen1, composedof50%CNF, 30%PP, and20%R, hastheleastcontentofmoistureforSampleA. ThecomputedaveragefortheSampleA-1was163.26%, 211.51%forSampleA-2, and234.33%forSampleA-3.

2)*Results for 3 cm Thickness of Acousti-Guard:*

TABLE 7:
MOISTURE ABSORPTION RESULTS OF ACOUSTI-GUARD SAMPLE B

Specimen	Moisture Absorption (%)			GWA
	24 hours	48 hours	72 hours	
1	168.01	194.49	233.08	198.53
2	186.76	230.66	258.89	225.44
3	155.67	192.78	205.15	184.54

Table 7 shows the results of Acousti-Guard sample B in moisture absorption test. Thefirstspecimenhadalengthofexposureof24hours, 48hours, and72hourshadobtained168.01%, 194.49%, and233.09%, respectively. Furthermore, thespecimen2hadthesamelengthofexposureandobtained moistureabsorptionof186.76%, 230.66%, and258.89%, respectively. While, thethirdspecimenwiththesamelengthofexposure, hadamoistureabsorptionof155.67%, 192.78%, and205.15%, respectively. Consequently, basedonthecomputedvalues, thesecondspecimenhadcontainedthehighestmoistureabsorptionforallthelengthofexposure. TheaveragemoistureabsorptionfortheSampleBwascomputedwhichhad198.53%forSampleB-1, 225.44%forSampleB-2, and184.54forSampleB-3. Basedonthecomputedaverage, therecommendeddesignmixtureforSampleBistheSample B-3sinceithastheleastcontentofmoistureabsorption.

3)*Results for 5 cm Thickness of Acousti-Guard:*

TABLE 8:
MOISTURE ABSORPTION RESULTS OF ACOUSTI-GUARD SAMPLE C

Specimen	Moisture Absorption (%)			GWA
	24 hours	48 hours	72 hours	
1	136.43	157.95	187.29	160.55
2	156.69	200	226.03	194.24
3	124.10	157.72	191.75	157.86

Theresultsofthemoistureabsorption, under table 8,forthe5cmthicknessofAcousti-Guardwerecalculatedsimilarlywiththeprevioussamplethicknesses. Forspecimen1, theresultsofthemoistureabsorptionwere136.43%forpanel witha24-hourexposure, 157.95%forpanelwitha48-hourexposure, and187.29%forpanelwitha72-hourexposure. Furthermore, theresultsforthespecimen2withanexposureof24hours, 48hours, and72hourshadacalculatedmoistureabsorptionof156.69%, 200%, and226.03%, respectively. Whilethespecimen3withthesamelengthofexposurehad124.10%, 157.72%, and191.75%, respectively, asthecomputedmoistureabsorption. Comparablewiththeprevioussamplethickness, thehighestmoistureabsorptionforthe5cmsamplethickness wasalsothespecimen2. Subsequently, specimen3containedtheleastcontentofmoistureforboth24-hourand48-hourexposure, however, specimen1hadtheleastmoistureabsorptionfor72-hourexposure. Similartotheprevioussamples, theaveragemoistureabsorptionofSampleCwasalsocomputedtodeterminethebestdesignmixture. SampleC-1hadanaverageof160.55%, 194.24%forSampleC-2, and157.86%forSampleC-3whichwascomputedastherecommendeddesignmixtureforthe SampleC.

4)*Results for Acoustic Foam Panel:*

TABLE 9:
MOISTURE ABSORPTION RESULTS OF ACOUSTIC FOAM PANEL

Commercial Acoustic Foam Panel	Thickness	Moisture Absorption (%)			GWA
		24 hours	48 hours	72 hours	
A	2 cm	2,111.1	2,133.3	2,211.1	2,151.9
B	3 cm	1,716.7	1,737.5	1,962.5	1,805.6
C	5 cm	1,757.9	1,886.8	1,926.3	1,857.02

Asshownontable9, thecomputedvaluesforthemoistureabsorptionoftheAcousticFoamPanelswerebiggerthanthecomputedvaluesoftheAcousti-Guard. Thefoampanelswerealsoexposedatasimilarlengthofexposureof24hours, 48hours, and72hours. FortheFoamPanel1witha2cmthickness, thecalculatedmoistureabsorptionwas2,111.11%, 2,133.33%, and2,211.11%, respectively. While, forthe3cmsamplethicknessofFoamPanel, thevalueswere1,716.67%, 1,737.5%, and1,962.5%, respectively. Lastly, forthe5cmthicknessoftheAcousticFoamPanel, theresultswere1,757.89%, 1,886.84%, and1,926.32%, respectively. GiventheresultsoftheAcousticFoamPanel, itwaspresentedandcalculatedthattheFoamPanel1, whichisthe2cm, hadthemostcontentofmoistureabsorption. FoamPanel2containedtheleastcontentofmoisturefor24-hourand48-hourexposure, andFoamPanel3hadtheleastcontentofmoisturefor72-hourexposure. Similarprocedures withtheAcousti-Guardsamples, theaveragemoistureabsorptionoftheCommercial acousticFoamPanelwasalsocomputedhaving2,151.85%forFoamPanelA, 1,805.56%forFoamPanelB, and1,857.02%forFoamPanelC.

B. ExperimentsResultsforFireResistance

Thetestwasconductedwithproceduresunder ISO-11925toknowthereactionofthesamplewhenexposedonfire. Theresearchersinitiallyweighedthesamplestoprovideareferencepointforevaluatinganyweightchangesduringthetest. Oncethesampleswereweighed, theywerepositionedwithinthefiretestingdevice, andthefiresourcewascalibratedtogenerateapredeterminedlevelofheatorflameintensity. Thesampleswerethenexposedtothefirefor30seconds, andafterthefiresourcewasremoved, theresearcherswaitedfortheflamestosubside, allowingthespecimenstocooldownbeforefurtherevaluation. Oncethesampleshadcooleddown, theywerereweighedandevaluatedtodetermineanychangesinweightandappearancethatoccurredduringthefiretest. Anylossinweightindicatedtheextentofmaterialdegradatio

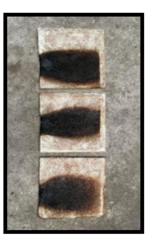


Figure 2. Acousti-Guard Sample A

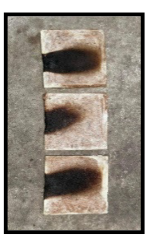


Figure 3. Acousti-Guard Sample B

Figure 4. Acousti-Guard Sample C

norcombustionthatoccurredduringexposuretothefire [29].

1)*Results for 2 cm Thickness Acousti-Guard:*

TABLE 10:
FIRE TESTING RESULTS FOR ACOUSTI-GUARD SAMPLE A

Acousti-Guard	Specimen	AFT < 3 secs	Fs > 150 mm	Flame Droplets
A	1	No, 5 sec	Yes, 10 sec	No
	2	Yes	Yes, 26 sec	No
	3	Yes	Yes, 14 sec	No

AsshowninTable10, thetestedmaterialsonthreedifferent2cmsamplesexhibited varyingdegreesoffireresistance. Withspecimen1aftertheinitialexposureof10seconds, specimen2after26seconds, andspecimen3after14secondstheflamespreadwasgreaterthan150mm. Despitetheflamespread, nodropletsorflamingdropletswereobservedduringanyofthetests. Specimen1continuedburningbrieflyafterthefiresourcewasgone, indicatingalowerleveloffireresistancecomparedtotheotherTwo. Whileallmaterialsignitedduringthetest, specimen2and3stoodoutfortheirfireresistance. Specimen2exhibitsadelayedspreadofflamesincontrasttotheflamespreadobservedinspecimen3.

2)*Results for 3 cm Thickness Acousti-Guard:*

TABLE 11:
FIRE TESTING RESULTS FOR ACOUSTI-GUARD SAMPLE B

Acousti-Guard	Specimen	AFT < 3 secs	Fs > 150 mm	Flame Droplets
B	1	No, 4 sec	Yes, 13 sec	No
	2	No, 4 sec	Yes, 11 sec	No
	3	Yes	Yes, 14sec	No

Table11showstheevaluationofthreedifferent3cmspecimens, allofwhichdemonstratedflamespreadwithinarelativelyclosetimeframe. Withspecimen1aftertheinitialexposureof13seconds, specimen2after11seconds, andspecimen3after14seconds, theflamespreadwasgreaterthan150mm. Althoughflamespreadwasobservedinalltests, noneshowedanydropletsorflamingdroplets. Specimens1and2bothsustainedcombustionforapproximately4secondsafterremovaloffiresource, suggestingcomparablelevelsoffireresistancebetweenthetwo. Conversely, Specimen3demonstratedasuperiordegreeoffireresistance. Uponremovalofthefiresource, novisibleflamewasobservedinSpecimen3. Thishighlightsthatspecimen3isbetteratstoppingfirefromspreadingcomparedtospecimen1and2.

3)*Results for 5 cm Thickness Acousti-Guard:*

TABLE 12:
FIRE TESTING RESULTS FOR ACOUSTI-GUARD SAMPLE C

Acousti-Guard	Specimen	AFT < 3 secs	Fs > 150 mm	Flame Droplets
C	1	Yes	Yes, 6 sec	No
	2	Yes	Yes, 15 sec	No
	3	Yes	Yes, 12 sec	No

AsshowninTable12, anevaluationoffireresistancewasconductedonthreedifferent5cmmaterialspecimens. Allthreesamplesexhibitedflamespread, withspecimen1aftertheinitialexposureof6seconds, specimen2after15seconds, andspecimen3after12secondstheflamespreadwasgreaterthan150mm. Noneofthespecimensproducedflamedropletsduringthetests. Despitetheinitialflamespread, allthreespecimensdisplayedaremarkableabilitytoself-extinguish. Novisibleflamespersistedonthreespecimensafterthefiresourcewasremoved. Butspecimen2stoodoutfromtheotherspecimensbecauseittakes15secondsforthespecimen2tohaveaflamespreadthatisgreaterthan150mm.

4) *Results for Acoustic Foam Panel:*

TABLE 13:
FIRE TESTING RESULTS FOR COMMERCIAL ACOUSTIC FOAM PANEL

Commercial Acoustic Foam Panel	Thickness	AFT < 3 secs	Fs > 150 mm	Flame Droplets
A	2 cm	No, 11 sec	Yes, 2 sec	Yes
B	3 cm	No, 15 sec	Yes, 2 sec	Yes
C	5 cm	No, 17 sec	Yes, 3 sec	Yes

Theevaluationofcommerciallyavailableacousticpanelsin Table13showsthatwithinsecondsofthetest, thespecimenexhibitedalackofresistancetofire, resultingintheirdissolutionandtheformationofflamedroplets. Thesedropletspersistedforvaryingdurations, withthespecimenof2cmthicknesssustainingcombustionfor11seconds, the3cmspecimenfor15seconds, andthe5cmspecimenfor17seconds. Thisshowsthematerial'svulnerabilitytofireanditsinabilitytowithstandcombustion, regardlessofthickness.

5) *Weight of the Samples Before and After the Fire Testing:*

TABLE 14:
WEIGHT OF THE ACOUSTI-GUARD SAMPLES BEFORE AND AFTER FIRE TESTING

Acousti-Guard	Thickness	Specimen	Weight Before	Weight After	Weight Loss %
A	2 cm	1	183	174	4.92
		2	194	185	4.64
		3	195	186	4.62
B	3 cm	1	267	260	2.62
		2	277	271	2.17
		3	291	287	1.37
C	5 cm	1	443	439	0.90
		2	441	436	1.13
		3	454	450	0.88

BasedonthedatashowninTable14, itshowsthattheacousti-guardexhibitsresistancetofire, withminimallossesanddamageduringexposure. Thisimpliesthatthematerialcaneffectivelywithstandtheeffectsoffire. Amongthespecimensofvariousthicknesses, specimen3, witha5cmthickness, exhibitedthehighestfireresistivity, withonlya0.88%lossinweight. Thisindicatesthat5cmacoustic-guardspecimen3hassuperiorperformancecomparedtotheotherspecimens.

TABLE 15:

WEIGHT OF THE COMMERCIAL ACOUSTIC FOAM PANEL BEFORE AND AFTER FIRE TESTING

Acoustic Foam Panel	Thickness	Weight Before	Weight After	Weight Loss %
A	2 cm	18	0	100
B	3 cm	24	0	100
C	5 cm	38	0	100

ThedatashowninTable15indicatethatthecommerciallyavailableacousticfoampanelappearstooffernoresistanceofire. Thismeansthematerialissusceptibletocatchingfireeasilyandlikelytoburncompletely, implyingthatitdoesn'thaveanyinherentfire-retardantpropertiestosloworstopthecombustionprocess. Acousticpanelsareoftenusedinbuildingstoimprovesoundproofing, butthislackoffireresistancemakesthemunsuitableformany applications, suchasinbuildingsorspaceswithstrictfiresafetyregulations.

C.ExperimentResultsforSoundAbsorptionTest

Forthisstudy, itutilizedtheimpedancetubesetupwhichisanothermethodoftestingthenormalincidenceacousticabsorptionofamaterialatitssurface. Thesampleswerecutfromitsoriginaldimensionto3-inchdiametertoperfectlyfitontheapparatus.

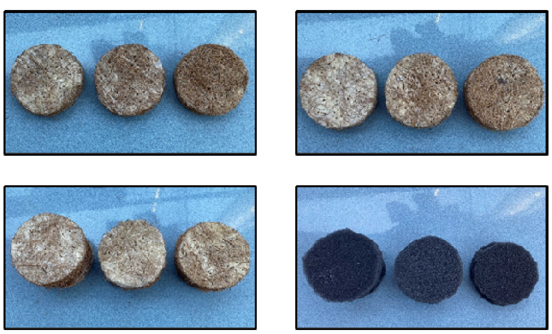


Figure5. SoundAbsorptionSpecimens

Utilizingtheequationsmentionedforlowerandupperfrequency, theactualworkingfrequencyrangeoftheimpedancetubeis180Hzto2,700Hz. Inorderforthestudytobeprecise, theworkingfrequencyrangeusedwillbe500-2,000Hztolimittheinconsistenciesathigherfrequency. Thesampleswillbeexposedonasoundwavefrequencygeneratedbythesoftwarewithdifferentfrequenciesmainly500Hz forlow-midrangefrequency, 1,150to1,500Hzformidrangefrequency, and2,000forupper-rangefrequency.

Figure6. MeasurementofSoundAbsorptionCoefficientonMatlabGUI

ThereflectedfrequencyiscollectedthroughtheMATLABGUIinordertoidentifythesoundabsorptioncoefficientoftheproduct. Inidentifyingthesoundabsorptioncoefficient, aformulaisused.

$$\alpha = 1 - |r|^2 \quad \text{Eq. 4}$$

Thetermαisthesoundabsorptioncoefficientofthematerialandtherisdefinedasthereflectioncoefficientofthefrequency. Tosolvefortheoverallcapacityofthespecimentoabsorbsoundfrequencythestudyutilizedgeneralweightedaverageassigningunits, u, of1,2,3, and4for500Hz, 1150Hz, 1500Hz, and2000Hz. Thestudyusedthegeneralweightedaveragebecausehigherfrequencydiffractslessthanlowerfrequencywhichmeansthe reflectedfrequencyresultsgreateronhigherfrequency. Highfrequencywavesaremoreaffectedbythesurfaceareaof amaterialthanlowerfrequencywaves [30]. Thesoundabsorptioncoefficient, α, willbethemultiplierfortheunitstoidentifytheoverallcapacityofthesample.

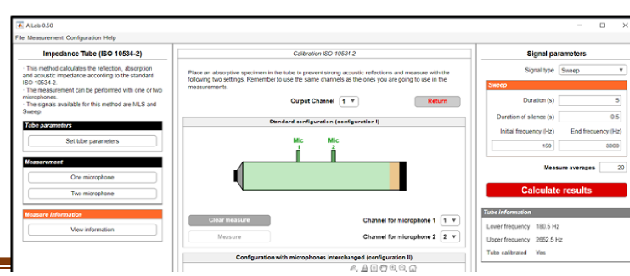
$$GWA = \frac{\Sigma\,(\alpha * u)}{\Sigma\, u} \quad \text{Eq. 5}$$

1) Results for 2 cm Thickness Acousti-Guard:

TABLE 16:
SOUND ABSORPTION COEFFICIENT OF ACOUSTI-GUARD SAMPLE A

Acousti-Guard	Sample	Sound Absorption Coefficient				GWA
		500 Hz	1150 Hz	1500 Hz	2000 Hz	
A	1	0.467	0.702	0.813	0.401	0.591
	2	0.503	0.770	0.709	0.737	0.712
	3	0.745	0.751	0.737	0.782	0.759

Table16showsthereflectioncoefficientofsampleAindifferentfrequencyranges: 500Hz, 1,150Hz, 1,500Hz, and2,000Hz. Basedontherecordedvalues, thesoundabsorptionofeveryspecimenisidentified. Forspecimen1, itshowsithasahigherabsorptionrateunder1,500Hzanda0.8



13soundabsorptioncoefficient. Under1,150Hz, specimen2acquiredthehighestsoundabsorptioncoefficient , havinga0.770. Whilethethirdspecimenoutperformsthefirsttwounder500 Hzand2,000Hz, havingasoundabsorptioncoefficientscoreof0.745and0.78 2, respectively. Thedifferenceinsoundabsorptioncoefficientbetweenthespecimensmaybeduetotheirdifferencesinsurfacearea, whichaffectstheplanarwaves. Thethirdspecimenhasthemostcapacitytoabsorbfrequency outofthethreespecimensundersampleA, whichhasaweightedaveragesoundcoefficientof0.759.

2)Results for 3 cm Thickness Acousti-Guard:

TABLE 17:
SOUND ABSORPTION COEFFICIENT OF ACOUSTI-GUARD SAMPLE B

Acousti-Guard	Sample	Sound Absorption Coefficient				GWA
		500 Hz	1150 Hz	1500 Hz	2000 Hz	
B	1	0.381	0.892	0.701	0.723	0.716
	2	0.879	0.852	0.822	0.883	0.858
	3	0.894	0.868	0.894	0.861	0.876

Table17representsthecollectedreflectioncoefficientandsoundabsorptioncoefficientdataofthespecimensofAcousti-guardsampleB. ThefirstspecimenundersampleBoutperformstheothertwospecimensunder1,150Hzhavingasoundabsorptioncoefficientof0.892. Moreover, thesecondspecimenhasthehighestsoundabsorptionunder2,000Hzhavingarecordedvalueof0.883. While, thethirdspecimenhasthehighestsoundabsorptioncoefficientunderthetwofrequencies, 500Hzand1,500Hz, andhasasoundabsorptioncoefficientof0.894onbothfrequencies. ThisshowsthatthethirdspecimenhasthehighestsoundabsorptioncapacityamongthethreespecimensofsampleBhavinganaverageof0.876.

3)Results for 5 cm Thickness Acousti-Guard:

TABLE 18:
SOUND ABSORPTION COEFFICIENT OF ACOUSTI-GUARD SAMPLE C

Acousti-Guard	Sample	Sound Absorption Coefficient				GWA
		500 Hz	1150 Hz	1500 Hz	2000 Hz	
C	1	0.618	0.717	0.635	0.465	0.582
	2	0.919	0.981	0.526	0.595	0.684
	3	0.483	0.880	0.915	0.933	0.872

Table18, showsthecollecteddataonsoundtestingforAcousti-GuardsampleC. ThefirstspecimenundersampleChasanaveragesound absorptioncoefficientof0.582whichisthelowestamongthethreespecimens. Furthermore, thesecondspecimenhasthehighestsoundabsorptioncapacityunder500Hz, and1,150Hzhavingarecordeddataof0.919and0.981respectively. Asforthethirdspecimen, ithasasoundabsorptioncoefficientof0.915and0.933on 1,500Hzand2,000Hzrespectivelywhichisthehighest. Therecordeddatashowsthatthethirdspecimenhasthe mostcapacitytoabsorbsoundhavinganaveragescoreof 0.872.

4)Results for 2 cm Acoustic Foam Panel:

TABLE 19:
SOUND ABSORPTION COEFFICIENT OF COMMERCIAL FOAM PANEL

Commercial Foam Panel	Thickness	Sound Absorption Coefficient				GWA
		500 Hz	1150 Hz	1500 Hz	2000 Hz	
A	2 cm	0.939	0.762	0.935	0.953	0.756
B	3 cm	0.937	0.881	0.888	0.888	0.792
C	5 cm	0.935	0.882	0.970	0.907	0.818

Table19showsthereflectioncoefficientandsoundabsorptioncoefficientofthecommercialfoampanelwhichwillbethecontrolofthestudy. FortheSampleAoffoampanel, ithasthehighestrecordedsoundabsorptioncoefficienton2,000Hzhavinga0.953score. ForsampleB, ithasanaverageof0.792andhasthehighestsoundabsorptioncoefficient, 0.937, underthe500Hzrange. AsforthesampleC, ithasarecordedsoundabsorptioncoefficientvalueof0.882and0.618under1,150Hzand1,500Hzrespectively. Furthermore, sampleChasthehighestsoundabsorptioncoefficientaveragewhichmeansthatithasthemostcapacitytoabsorbsoundfrequencyamongtheothersamplesforcommercialfoampanels.

5)ComparisonofHighestSoundAbsorptionCoefficientCapacityofAcousti-GuardSamplesandCommercialFoamPanel:

TABLE 20:
COMPARISON BETWEEN ACOUSTI-GUARD AND COMMERCIAL FOAM PANEL

Acousti-Guard	Sample	GWA	Commercial Foam Panel	GWA
A	3	0.759	A	0.756
B	3	0.876	B	0.792
C	3	0.872	C	0.818

Table20showsthesoundabsorptioncoefficientofthesamplesofAcousti-Guardandthecommercialfoampanel. Thehighestsoundabsorptioncoefficientofpersamplewaschosentocompareontheexistingcommercialfoampanelonthe market. ForthesampleA, thathas2cmthickness, thesoundabsorptioncoefficientoftheAcousti-Guardisalmostequaltotheperformanceofthecommercialfoampanel. Fromthetablefor2cm., itshowsthatsoundabsorptioncoefficientofAcousti-Guardisalmostsimilarthrough-outthefrequencyrange, whilethecommercialfoampanelhavelowsoundabsorption capacityonotherfrequencies. Moreover, forthesampleBthathas3cmthickness, theAcousti-Guardperformedbetterhavingasoundabsorptioncoefficientof0.876. UndersampleC, thathas5cmthickness, theAcousti-Guardoutperformsalsothecommercialfoampanelbyslight difference.

6) ComparisonofAcousti-GuardandCommercialFoamPanelusingT-testAnalysis: Thet-testisacommonwayforresearcherstocomparetheaveragesoftwogroups. Itusesthet-distribution, whichdependsonsamplesize, todecideiftheresultsareimportant [31]. Theresearchersutilizedthet-testanalysistoknowifthereisasignificantdifferencebetweenthedevelopedAcousti-Guardandcommercialfoampanelintermsoftheirsoundabsorptioncapacity. Havingasmallnumberofdataisoneofthereasonsresearchers makeuseoft-testanalysis. Theresearchersusedthesoundabsorptioncoefficientofbest designmixtureineveryAcousti-guardsampleatrangingfrequencyincomparisontothecommercialfoampanelasthedatatosolveforthet-valueofeachsample. Insolvingthet-value, theequationisused,

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \quad Eq.6$$

Thevariablesneededtosolvethet-valuearethegeneralweightedmean ($\bar{x}$) andweightedstandarddeviation, softhetwosamplebeingcompared. Thenumberofdata or number of test, n,isalsoneededtocomputethet-valueandthedegreeoffreedom, df. Thegeneralweightedmeanissolvedusingtheequationno. 5. Weightedstandarddeviationanddegreeoffreedomiscomputedthroughthisequation,

$$s = \sqrt{\frac{\sum_{i=1}^{n} w_i (x_i - \bar{x})^{2}}{\sum_{i=1}^{n} w_i \left(\frac{n-1}{n}\right)}} \quad Eq.7$$

$$df = [(n_1 + n_2) - 2] \quad \text{Eq. 8}$$

*7)**NullandAlternativeHypothesis:*** Thenullhypothesis, Ho, ofthecomparisonisifthereisnosignificantdifferencebetweenAcousti-Guardandcommercialfoampanelsintermsofsoundabsorptioncapacity. Whilethealternativehypothesis, Ha, ifthereissignificantdifferencebetweenAcousti-Guardandcommercialfoampanels.

Ho = ThereisnosignificantdifferencebetweenAcousti-Guardandcommercialfoampanelsintermsofsoundabsorptioncapacity.

Ha = ThereisasignificantdifferencebetweenAcousti-Guardandcommercialfoampanelsintermsofsoundabsorptioncapacity.

Theconfidencelevelwasconsideredat95%andthealpha valuewillbe0.05. Thelimitofthet-value, two-tailedtest, basedonat-distributiontablehavinganalphaof0.05anddegreeoffreedomof6willbe ± 2.477. Thiswillbethefactorifthenullhypothesisofthestudywillberejectedoraccepted. Ifthet-valueislessthan -2.477andgreaterthan +2.477, thenullhypothesiswillberejected. However, ifthet-valueisgreaterthan -2.477andlessthan +2.477, thenullhypothesiswillbeaccepted. Theconditionbelowshowsthepossibleresultsofthet-testanalysis.

-2.477>**t-value**> +2.477 ;**RejectHo**

-2.477<**t-value**< +2.477 ;**FailedtorejectHo**

8)ComparativeAnalysisofAcousti-GuardandCommercialFoamPanelusingT-test:

TABLE 21:
RESULT OF T-TEST ANALYSIS FOR ACOUSTI-GUARD SAMPLE A AND COMMERCIAL FOAM PANEL SAMPLE A

Sample	n	x̄	s	t-value	-2.477 < t-value < 2.477
Acousti-Guard A-3	4	0.759	0.023	0.019	Accept Ho
Foam Panel A	4	0.756	0.261		

Thedatapresentedintable21comparesthesoundabsorptioncoefficientoftwomaterials: Acousti-GuardA-3andacommerciallyavailableacousticfoampanel. TheweightedmeanforAcousti-GuardA-3is0.759withastandarddeviationof0.023, whilethecommercialfoampanelhasaweightedmeanof0.756andastandarddeviationof0.261. Thecalculatedt-value, derivedfromallthevalues, is0.019. Thesignificanceofthet-valuelieswithintherangeof -2.477to +2.477, suggestingthatitfallswithinthisinterval. Consequently, thenullhypothesisisaccepted, indicatingthatthereisnosignificantdifferencebetweenAcousti-Guardandthecommercialfoampanelconcerningtheirsoundabsorptioncapacity. Thisinterpretationimpliesthat, basedonthedataprovided, bothAcousti-GuardA-3andthecommercialfoampanelperformcomparablyintermsofsoundabsorption. Therefore, whenconsideringsoundabsorptionpropertiesalone, thereisnodiscernibleadvantageofonematerialovertheother.

TABLE 22:
RESULT OF T-TEST ANALYSIS FOR ACOUSTI-GUARD SAMPLE B AND COMMERCIAL FOAM PANEL SAMPLE B

Sample	n	x̄	s	t-value	-2.477 < t-value < 2.477
Acousti-Guard B-3	4	0.876	0.018	0.931	Accept Ho
Foam Panel B	4	0.756	0.179		

Theprovideddataintable22highlightsthesoundabsorptioncoefficientsoftheoptimaldesignmixturesforeachsampleofAcousti-GuardB-3andacommerciallyavailablefoampanel. Acousti-GuardB-3showsaweightedmeanof0.876andastandarddeviationof0.018, whilethecommercialfoampaneldisplaysaweightedmeanof0.756withastandarddeviationof0.179. Uponanalysis, thecalculatedt-valueisdeterminedtobe0.932. Giventhatthet-valuefallsbetweentherangeof -2.477to+2.477, itisdeemedsignificantwithinthisinterval. Consequently, thenullhypothesisisaccepted, indicatingnosubstantialdifferencebetweenAcousti-GuardB-3andthecommercialfoampanelintermsofsoundabsorption. ThisinterpretationsuggeststhatbothAcousti-GuardB-3andthecommercialfoampaneloffercomparablesoundabsorptionperformance.

TABLE 23:
RESULT OF T-TEST ANALYSIS FOR ACOUSTI-GUARD SAMPLE C AND COMMERCIAL FOAM PANEL SAMPLE C

Sample	n	x̄	s	t-value	-2.477 < t-value < 2.477
Acousti-Guard C-3	4	0.759	0.151	0.50	Accept Ho
Foam Panel C	4	0.818	0.152		

Theanalysisoftable23revealsthesoundabsorptioncoefficientsoftheoptimalmixturesforAcousti-GuardC-3andacommerciallyavailablefoampanel. Acousti-GuardC-3exhibitsameanabsorptioncoefficientof0.759withastandarddeviationof0.151, whilethefoampanelshowsameanof0.818andastandarddeviationof0.151. Statisticalevaluationyieldsat-valueof0.50, fallingwithintherangeof -2.477to +2.477, indicatingsignificancewithinthisinterval. Consequently, thenullhypothesisisupheld, suggestingnosubstantialdifferenceinsoundabsorptioncapacitybetweenAcousti-GuardC-3andthecommercialfoampanel. Thisinterpretationunderscoresthecomparablesoundabsorptionperformanceofbothmaterials, indicatingnosignificantadvantageofoneovertheothersolelybasedonthiscriterion.

VI. CONCLUSIONS

This study aims to produce an acoustic panel with the use of cocos nucifera fibers, and paper pulp and examine its capacity in terms of its moisture absorption, fire resistivity, and sound absorption. Based on the findings and results of this study, the following conclusions were drawn:

Using natural fibers could be an alternative material for reducing the reverberation of sound as long as the structure of the panel is porous, where it could efficiently dissipate sound energy. The thickness of the panel also matters in dissipating sound energy, as it could absorb more frequency through its structure. Due to the rigidity of the panel and the inherent property of polyurethane resin as a fire retardant, Acousti-Guard could resist the continuous ignition of fire.

One of the main important tests of the study is to identify if Acousti-Guard can efficiently absorb sound using natural fibers. Based on the results, all samples of Acousti-Guard performed well on the sound test. Specifically, the Acosuti-Guard sample C-3 performed better on all of the tests but fell short by a minimal margin on the sound absorption coefficient, wherein the highest average performance is 0.876, which is the sample B-3, and the Acousti-Guard sample C-3 has 0.872

Based on the findings, the Acousti-Guard is as effective as the commercial foam panel in absorbing sound as long as the inside structure of the Acousti-Guard is porous. Furthermore, on moisture absorption and fire resistivity, the Acousti-Guard has better results compared to the commercial foam panel as it absorbs moisture and does not have the capacity to resist fire for a longer exposure.

Acousti-Guard is also economically comparable to commercially available foam panels on the market and also aids in reducing natural waste and improving environmental issues. In the study, the most economically comparable sample was specimen 3 of sample C. It had a rounded overall cost of ₱63 with dimensions of 25 cm x 25 cm. When considering the price per square foot, the cost is estimated approximately at ₱93. However, the commercial panel boards from markets with installation can cost up to ₱300. While, in this study, the cost is estimated to ₱150 that includes installation services, making it comparable in price to commercial panel boards.

Following the standard sizes for panel board,

TABLE 24:
COST OF ACOUSTI-GUARD PANEL BOARD IN STANDARD DIMENSIONS

Sample	Thickness	Dimension	Price
Acousti-Guard Sample A	2 cm	2 ft x 4 ft	₱430
		4 ft x 8 ft	₱1,715
Acousti-Guard Sample B	3 cm	2 ft x 4 ft	₱550
		4 ft x 8 ft	₱2,190
Acousti-Guard Sample C	5 cm	2 ft x 4 ft	₱750
		4 ft x 8 ft	₱2,999

In Table 24, the estimated costs of Acousti-Guard are presented in accordance with standard sizes commonly found on the market. For Acousti-Guard sample A, with a thickness of 2 cm, the price is ₱430 for the dimensions 2 ft x 4 ft and ₱1,715 for 4 ft x 8 ft. The prices of Acousti-Guard sample B, which has a thickness of 3 cm, are ₱550 for 2 ft x 4 ft and ₱2,190 for 4 ft x 8 ft. Meanwhile, the price range of Acousti-Guard sample C is estimated to be ₱750 for 2 ft x 4 ft and ₱2,999 for 4 ft x 8 ft. These estimated prices for Acousti-Guard are economically comparable to acoustic insulation panels offered on the market, which usually fall within a price range of ₱2,000 to ₱4,500.

The density of Acousti-Guard is calculated using the dimensions and weight of the samples developed in the study.

TABLE 25:
DENSITY OF ACOUSTI-GUARD

Acousti-Guard	Thickness	Dimension	Mass	Density
A	0.02 m	0.25 m x 0.25 m	0.2 kg	160 kg/m^3
B	0.03 m	0.25 m x 0.25 m	0.29 kg	154.67 kg/m^3
C	0.05 m	0.25 m x 0.25 m	0.45 kg	144 kg/m^3

Table 25 shows the computed values of the density of the developed Acousti-Guard, which varies in thickness. Samples A, B, and C of Acousti-Guard have the same dimensions of 0.25 m x 0.25 m but differ in thickness. Sample A, with a thickness of 0.02 m and a mass of 0.2 kg, has a density of 160 kg/m^3. Sample B, with a thickness of 0.03 m and a mass of 0.29 kg, has a density of 154.67 kg/m^3. Sample C, with a thickness of 0.05 m and a mass of 0.45 kg, has a density of 144 kg/m^3. The density of the material is important for its sound absorption capacity and installation on walls. Most commercially available acoustic foam panels have densities ranging from 200 kg/m^3 to 400 kg/m^3. Knowing the weight of the product before installation is crucial to determine the necessary strength of the support structure, ensuring it can safely and effectively bear the added load from the product.

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